

AD-A031 404

NAVAL RESEARCH LAB WASHINGTON D C
A CRITICAL ANALYSIS OF CLIMATOLOGICAL WIND DATA USED IN THE FOR--ETC(U)
SEP 76 M R SCHOEBERL, S T ZALESK
NRL-MR-3366

F/G 4/2

UNCLASSIFIED

NL

[OF]

AD
A031404

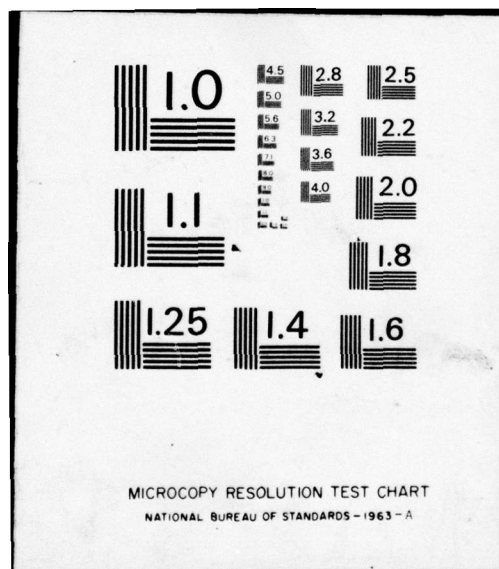


END

DATE

FILMED

12-76



BS. (12)
NRL Memorandum Report 3366

A Critical Analysis of Climatological Wind Data Used in the Forecast of Radioactive Debris Cloud Movement

MARK R. SCHOEBERL

*Science Applications Inc.
McLean, Virginia 22101*

and

S. T. ZALESAK

*Plasma Dynamics Branch
Plasma Physics Division*

September 1976

This research was sponsored by the Defense Nuclear Agency under subtask S99QAXHC065,
work unit 08, work unit title High Altitude Debris.



NAVAL RESEARCH LABORATORY
Washington, D.C.

AD A031404

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

9 REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 3366	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A CRITICAL ANALYSIS OF CLIMATOLOGICAL WIND DATA USED IN THE FORECAST OF RADIOACTIVE DEBRIS CLOUD MOVEMENT.		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem.
7. AUTHOR(s) Mark R./Schoeberl and S. T./Zalesak		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Nuclear Agency Washington, D.C. 20305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem H02-36 DNA Project S99QAXHC065
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12/24P		12. REPORT DATE September 1976
		13. NUMBER OF PAGES 38
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) 16 NRL-HQ2-36 DNA-NWED-QAXH		17 C065
18. SUPPLEMENTARY NOTES This work was sponsored by the Defense Nuclear Agency under Subtask S99QAXHC065, work unit 08, work unit title High Altitude Debris.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Mesosphere Climatology Wind fields		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → Groves' (1969, 1972) climatological wind field data is critically examined for the purpose of forecasting radioactive debris cloud motion. It is found that the data base used by Groves is too sparse to be climatologically representative. We also find that the wind field given by Groves implies the existence of heat and momentum sources not believed to be present in the upper atmosphere, and furthermore, the wind fields are unstable to eddy perturbations. These results suggest that the climatological averaging process is biased by poor spatial and temporal resolution. Eddy motions are thus averaged as part of the mean flow. → next page (Continues)		

20. Abstract (Continued)

cont.

It is concluded that for the purpose of forecasting debris cloud motion, climatological wind fields are useful for producing idealized calculations but are probably not very representative of the actual wind fields at a given time and place. A better model for such purposes would be a theoretical forecast model initialized on a regular basis from satellite radiance data.

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	AVAIL. and/or SPECIAL
A	

CONTENTS

I. INTRODUCTION	1
II. UPPER ATMOSPHERIC WIND DATA	3
III. HEAT AND MOMENTUM SOURCES IN THE UPPER ATMOSPHERE	6
IV. STABILITY OF MEAN ZONAL FLOW	9
V. SUMMARY AND CONCLUSION	11
REFERENCES	13

A CRITICAL ANALYSIS OF CLIMATOLOGICAL WIND DATA USED IN THE FORECAST OF RADIOACTIVE DEBRIS CLOUD MOVEMENT

I. INTRODUCTION

It is of considerable importance to communication system performance (ELF, VLF, HF) in a nuclear environment to be able to predict debris cloud transport in the mesosphere. Zalesak and Coffey (1975) have shown that transport can profoundly alter the location of radioactive debris clouds. The subsequent beta decay within the cloud results in long lasting, widespread ionization that can severely affect the performance of communication systems. Accurate prediction of system performance depends critically on our ability to describe the movement of debris patches by mesospheric wind systems.

The purpose of this report is to assess the present method by which the spread of radioactive debris clouds in the upper atmosphere is determined and to suggest guidelines for future research. The current technique used to forecast debris cloud advection uses a Lagrangian computer code with model wind fields (Zalesak and Coffey, 1975). The wind fields are given by Groves (1969), CIRA (1972). These wind fields, being based upon many years of observational data, represent the best statistics available at the time the study was undertaken. The results produced by Zalesak and Coffey clearly hinge upon the accuracy of the wind field data. It is thus important to examine the data carefully and ask if these wind fields actually give an accurate representation of the upper atmospheric motions relevant to determining debris cloud advection. Groves' data are an "average" or climatological representation of the wind field from which some spatial and temporal fluctuations have been removed by the averaging process. If these fluctuations are quite small, then the averaged data may be used to accurately forecast the transport of trace constituents. On the other hand, if the fluctuations are large, the actual wind field may rarely

Note: Manuscript submitted August 30, 1976.

resemble the climatological wind field and resulting debris cloud forecasts based upon the latter will be reliable only in a climatological sense.

In this report the wind fields given by Groves shall be examined with the following criteria. First, we can, to some extent, quantitatively assess variability within the wind field data by examining the standard deviation of the climatological average published by Groves (CIRA, 1972).

Second, we examine the consistency of the data with theoretical models of upper atmospheric dynamics. While inconsistency between empirical models and theoretical models does not necessarily imply unreliable data, consistency allows us to use theoretical models where empirical data may be lacking or difficult to obtain. From this viewpoint we can determine if the wind structure of the upper atmosphere as computed from theoretically postulated heat and momentum sources bears any resemblance to the empirical wind structure given by Groves. Or conversely, we can compute the implied heat and momentum sources required to maintain Groves' wind model and compare with known sources. Both aspects of this problem will be discussed.

Third, the zonal wind model of Groves is tested for stability to small wave perturbations. Instability probably implies the presence of large scale eddy mixing which could greatly affect the transport of radioactive debris.

Within the body of this report the data and the observed variability of the data are discussed in Part II. The implied heat and momentum sources derived from Groves' data and the theoretically predicted heat and momentum sources are compared in Part III. Stability computations for Groves' wind model are presented in Part IV. In Part V we conclude that Groves' wind fields are probably inadequate for debris cloud advection forecast purposes and suggest that theoretical prediction models currently under development can be used to provide more reliable results.

II. UPPER ATMOSPHERIC WIND DATA

Wind observations above 30 km and below 150 km are principally obtained through rocket based techniques. At high altitudes a meteorological rocket releases an object or chaff which is tracked by radar as it falls. Lateral motion of the falling object then yields horizontal wind data and the local density of the atmosphere may be computed by observing the rate of fall. Compared with radiosonde observations used below 30 km, rocket methods are very expensive and technologically complex. As a result, the network of rocket launching stations is quite sparse and regular observations are taken only weekly. Figure 1 shows the station locations for the Meteorological Rocket Network (MRN).

The rocket data obtained through the MRN facilities contains both systematic and random deviations or "errors." Both kinds reduce the usability of the derived climatological wind models for forecasting. We may further subdivide the deviations into those due to measurements (e.g., faulty radar techniques) and those due to the phenomena (e.g., small scale eddies inadequately resolved by the MRN grid). Quiroz (1969) discusses systematic and random measurement deviations at length and his findings will not be reviewed here. Measurement error of the systematic type is assumed to be negligible, whereas random error associated with the measurements is assumed to be removed by climatological averaging.

Probably the most obvious source of systematic deviations associated with phenomena in the upper atmosphere is that produced by the presence of tidal winds. Most MRN data is taken at local noon. Thus, if regular diurnal and semidiurnal tidal wind components are present, they will be interpreted in any local climatological analysis as a component of the mean wind. Lindzen (1967) has computed the amplitude of the tidal winds up to 100 km and has found that winds

associated with the solar semidiurnal and diurnal tides may be as large as 100 ms^{-1} at 100 km in the zonal direction. Measurement of tidal winds below 60 km shows general agreement with Lindzen's computation with some disagreement evident above 60 km (Glass and Spizzichino, 1974).

Groves' wind model presented in CIRA (1972) (also Groves, 1969) has been constructed by grouping MRN and other data into monthly or bimonthly sets. The data within a set have been further subdivided into four hour time groups depending on the local time the data were taken. The average within each group was computed as well as the mean deviation. Above 60 km Southern Hemisphere data were assumed to be equal to Northern Hemisphere data. Final wind model values were computed by an iterative scheme involving the average of the mean deviations and the average of the group averages and a weighting formula. Using an average of the group averages is equivalent in some sense to a daily average. Provided large monthly changes in the amplitude and phase of the tidal components do not occur and data samples are present within each group, this method should eliminate the systematic error introduced by tides. In reality, however, many groups lack data altogether above 60 km so that model points are based upon only one or two groups (cf. CIRA, 1972). We may conclude then that high altitude winds presented by Groves probably contain considerable bias from tidal winds superimposed upon the zonal and meridional mean winds.

Essentially, the systematic deviation introduced by tidal components results from inadequate temporal resolution of the zonal mean wind components. Inadequate spatial resolution can also introduce systematic deviations. In particular, quasistationary planetary scale waves as well as tides have wind components which vary very slowly over horizontal distances on the order of 5,000 to 10,000 km. From Figure 1 it is apparent that MRN stations are principally located in the northern part of the Western Hemisphere,

and thus the network will be unable to resolve wind components associated with very long zonal scales.

A comparison of West European and North American data presented in CIRA (1972) indicates the presence of these long spatial waves. For example, in January the mean zonal wind velocity over North America is $\sim 20 \text{ ms}^{-1}$ at 50 km at 55°N , while the mean zonal wind velocity over Europe is $\sim 80 \text{ ms}^{-1}$. The difference is presumably attributable to the long wave wind components. The difference between North American and European mean zonal wind velocities below 60 km is largest during winter and is consistent with the observed strength of planetary scale waves below 30 km (van Loon, et al., 1973). Theoretical calculations of the amplitude of stationary planetary waves in the upper atmosphere indicate that these waves may have sizable amplitudes up to the mesopause and may generate zonal wind components as large as $20 \text{ ms}^{-1} - 30 \text{ ms}^{-1}$ in the mesosphere and lower thermosphere (Schoeberl, 1975).

Small scale eddies are probably also present in the upper atmosphere generated by baroclinic instability near the stratopause. If their horizontal length scales are much smaller than 1000 km, then the spatial distribution of the MRN network will be inadequate to properly resolve them. These eddies will appear as random fluctuations in the MRN data. For the purpose of predicting the location of debris clouds, these eddies may be as important as the zonal mean flow. No information is available from Groves' models on their possible structure or amplitude.

All of the phenomena discussed above contribute to the standard deviation of the MRN data as error. In Figure 2 the model values of the mean zonal wind in January and July above 60 km given by CIRA (1972) and the standard deviation of the observations from the model values are given. Two important features are apparent. First, it is clear from the large number of missing standard deviations how limited the data base actually is. Second, we note that the standard deviation is often larger than the mean value indicating that climatological state of the wind field (Groves' model) occurs as an exception rather than the rule.

III. HEAT AND MOMENTUM SOURCES IN THE UPPER ATMOSPHERE

The mean zonal circulation is driven by external heat and momentum sources. In some cases, these sources may be theoretically computed and a circulation model developed to compare with observations (Leovy, 1964; Baker and Strobel, 1975_a, 1975_b). Alternatively, a wind model derived from data can be used to calculate the implied heat and momentum sources which may then be compared to theory (Ebel, 1974). We shall consider the consistency of computed wind models and implied heat and momentum sources with their observed and theoretical counterparts in this section.

Leovy (1964) showed that the westerly stratospheric jet observed in the winter hemisphere and the easterly jet observed in the summer hemisphere arise from the meridional ozone heating gradient in the stratosphere. Mean zonal wind maximums of 80 ms^{-1} were computed by Leovy associated with mean meridional wind velocities of 0.7 ms^{-1} . The mean zonal wind velocities fluctuate in magnitude throughout the winter (Belmont, et al., 1975), but 80 ms^{-1} is in relatively good agreement with Groves' (1969) climatological value considering many of the simplifications used by Leovy. However, Groves' mean meridional velocities are an order of magnitude larger than those computed by Leovy and Baker and Strobel. Furthermore, their meridional winds blow from the summer pole to the winter pole, while Groves' meridional winds are quite variable depending upon latitude and altitude.

The discrepancy between these computations and Groves' data may be due to several factors. First, assuming Groves meridional winds are correct, the mean zonal winds (which result from Coriolis torques acting upon northward or southward moving flow) may be computed by the following equation.

$$\bar{u} = \frac{2\overline{v} \sin \theta}{\beta_R} \quad (1)$$

where Ω is the earth's frequency of rotation and θ is the latitude. β_R is the Rayleigh friction coefficient; \bar{v} is the zonally averaged meridional velocity of the wind, and \bar{u} is the zonally averaged zonal velocity. β_R is unknown but has been estimated to be $\sim 10^{-6} \text{ sec}^{-1}$ (Leovy, 1964). Using 10 ms^{-1} for \bar{v} , which is the order of magnitude given by Groves (1969), gives $\bar{u} \approx 1000 \text{ ms}^{-1}$, which is inconsistent with the \bar{u} values also given. If \bar{u} and \bar{v} are assumed correct, we are forced to conclude that equation (1) does not describe the correct relationship between \bar{u} and \bar{v} , and the addition of a momentum source term, M , of unknown value to the righthand side of Equation (1) is required to form a consistent equation between \bar{u} and \bar{v} . It is also apparent that the magnitude of M must be quite large. The presence of eddies which could contribute to M are known to exist in winter but are generally absent in summer (Kriester, 1972). However, large values of \bar{v} are also indicated by Groves for the summer, so this explanation is implausible.

A more complete calculation of the required momentum and heat sources needed to maintain the Groves model winds in the mesosphere (70 - 100 km) has been carried out by Ebel (1974). The strength of the heat sources is shown in Figure 3 for solstice conditions. A comparison with the computed heat sources from Park and London (1973), Figure 4, indicates that the value of the heat sources required to maintain the Groves wind field is roughly an order of magnitude too large. Thus, in agreement with our above arguments, it is improbable that Groves' \bar{v} values are consistent with the \bar{u} values given.

Equation (1) is the zonal mean momentum equation. If, as suggested in Section II, the MRN data is biased by tidal and stationary planetary waves, then Equation (1) should be written as

$$\beta_R u_g + \frac{\partial u_g}{\partial t} + 2\Omega v_g \sin \theta = \frac{1}{a \cos \theta} \frac{\partial \phi}{\partial \lambda} \quad (2)$$

where ϕ is the geopotential and the subscript g indicates the values given by Groves (1969) which are now not assumed to be zonal means. Both tidal and long wave components can theoretically produce

meridional wind velocities as large as those reported in Groves' model (Lindzen, 1967; Schoeberl, 1975) and in all probability it is these components that are reported by Groves. The larger velocities permitted by Equation (2) arise from the presence of a zonal pressure gradient force on the righthand side and the second term on the left-hand side which is an inertial term. Both of these terms are much larger than the term $\beta_R u_g$ for planetary scale and tidal motions. The value of v_g is thus not coupled to u_g alone. For tidal and planetary scale waves, both observation and theory indicate that $u \sim v \sim 10-20 \text{ ms}^{-1}$ in the stratosphere. These values of v are more consistent with the values of v_g and suggest that the data are indeed biased by planetary wave and tidal components.

IV. STABILITY OF MEAN ZONAL FLOW

While it is nearly impossible to quantitatively estimate the magnitude of the bias that long wave components and smaller scale eddy components have introduced into Groves' wind fields, we can gain some estimate through a stability analysis. Our argument is as follows: If the mean zonal wind field is stable to wave perturbations, then any finite amplitude eddy disturbances can be assumed to arise from boundary (tropospheric) forcing. If the flow field is unstable, then finite amplitude disturbances may arise spontaneously from infinitesimal, local disturbances.

It has been shown by Charney and Drazin (1961) that only large planetary scale eddies can propagate into the upper atmosphere. Synoptic scale disturbances observed in the troposphere will remain trapped below the stratosphere. Dickinson (1973) and Simmons (1975) have shown that the long wave components are the fastest growing modes for unstable flow fields similar to those observed in the upper stratosphere and mesosphere. A computation of the stability of the observed zonal mean flow field as given by Groves (CIRA, 1972) may thus indicate where large amplitude eddy components could arise.

Using the Charney-Stern stability criteria (Charney and Stern, 1962) we compute numerically the stability of Groves' mean zonal wind field. In the stability criterion for an atmosphere bounded by rigid walls, a necessary condition for instability is that Q , defined as

$$Q \equiv 2(\Omega + \bar{\omega}) - \frac{\partial^2 \bar{\omega}}{\partial \theta^2} + 3 \tan \theta \frac{\partial \bar{\omega}}{\partial \theta} - \sin^2 \theta e^z \frac{\partial}{\partial z} \frac{e^{-z}}{S} \frac{\partial \bar{\omega}}{\partial z} \quad (3)$$

where $z = \ln(p_0/p)$, $\bar{\omega} = \bar{u}/a \cos \theta$, and p is pressure, does not change sign within the bounded region.

Figures 5 and 6 show the value of Q computed numerically for parts of the CIRA (1972) and CIRA (1965) model atmospheres, respectively. Also shown is a plot of the corresponding flow pattern. It is evident that these model atmospheres have unstable regions, particularly near the stratopause and near the pole at all levels, as indicated by the negative values of Q . A term by term examination of Equation (3) indicates that the sign change in Q is principally a result of sign changes in the last term. Instabilities developing from this flow pattern would thus be primarily baroclinic.

The assumption that Groves' wind models characterize the mean zonal flow field is, of course, introduced in this analysis. One example where such an assumption is certainly incorrect is evident in Figure 4 where a patch of negative Q appears to 50°N and 30 km in the wind model taken from North American data. No such region appears in the computations based upon European data. The source of the sign change in Q is the appearance of a region of easterly winds in the midst of a westerly jet in the North American data. The winds in this region are probably strongly biased by planetary waves as discussed in Section II and not zonal means; hence, the Charney-Stern stability criteria does not apply.

The existence of high frequency motions at the stratopause have been observed by Leovy and Akerman (1973), and these motions may be due to unstable wind configurations such as those given by the CIRA (1972, 1965) model atmospheres. In any event, the fact that Groves' models are unstable indicates that either eddy components of the wind have biased the data to such an extent that the wind profile appears unstable; or, that eddy components are present with sizable amplitudes.

V. SUMMARY AND CONCLUSION

The usability of Groves' climatological wind fields for forecasting debris cloud advection has been assessed from three different viewpoints. We have briefly discussed the data and suggested possible biasing of the wind field by tidal, planetary wave, and small scale eddy motions. An examination of the standard deviation of the data indicates that the actual structure of the wind field in the upper atmosphere rarely resembles the climatological data given by Groves.

We have also examined the heat and momentum sources implied by wind fields. The values of \bar{v} given by Groves (1969) are an order of magnitude too large, and imply heat and momentum sources much larger than expected from theory. We conclude the \bar{v} values actually represent meridional velocities associated with planetary scale waves and tides.

Finally, we note that Groves' zonal wind fields are unstable, especially near the polar stratopause. The instability could imply the existence of large amplitude eddy components in the wind field for that region. We conclude that while Groves' wind fields probably represent the best available data they nevertheless inadequately represent the structure of the upper atmosphere for the purposes of forecasting the advection of debris clouds.

An alternative to the use of Groves' wind fields to forecast movement of a debris cloud is the use of a theoretical prediction model which can be initialized on a regular schedule or at the moment of debris cloud release. Such a model is presently used in the lower atmosphere and gives reliable forecasts up to three days in advance. With some adaptations, this type of model can be constructed for the upper atmosphere and can be initialized with satellite radiance data. This data, which is in the form of temperature fields, is currently available up to 60 km (Chapman, et al., 1972) and will soon be available up to 80 km and higher. Upper atmosphere forecast models are under development at NRL at present. Madala, et al., (1975) have shown that

tidal winds can be adequately simulated with a spectral forecast model, and Schoeberl (1976) has been able to determine theoretically the structure of planetary waves in the upper atmosphere using a similar method.

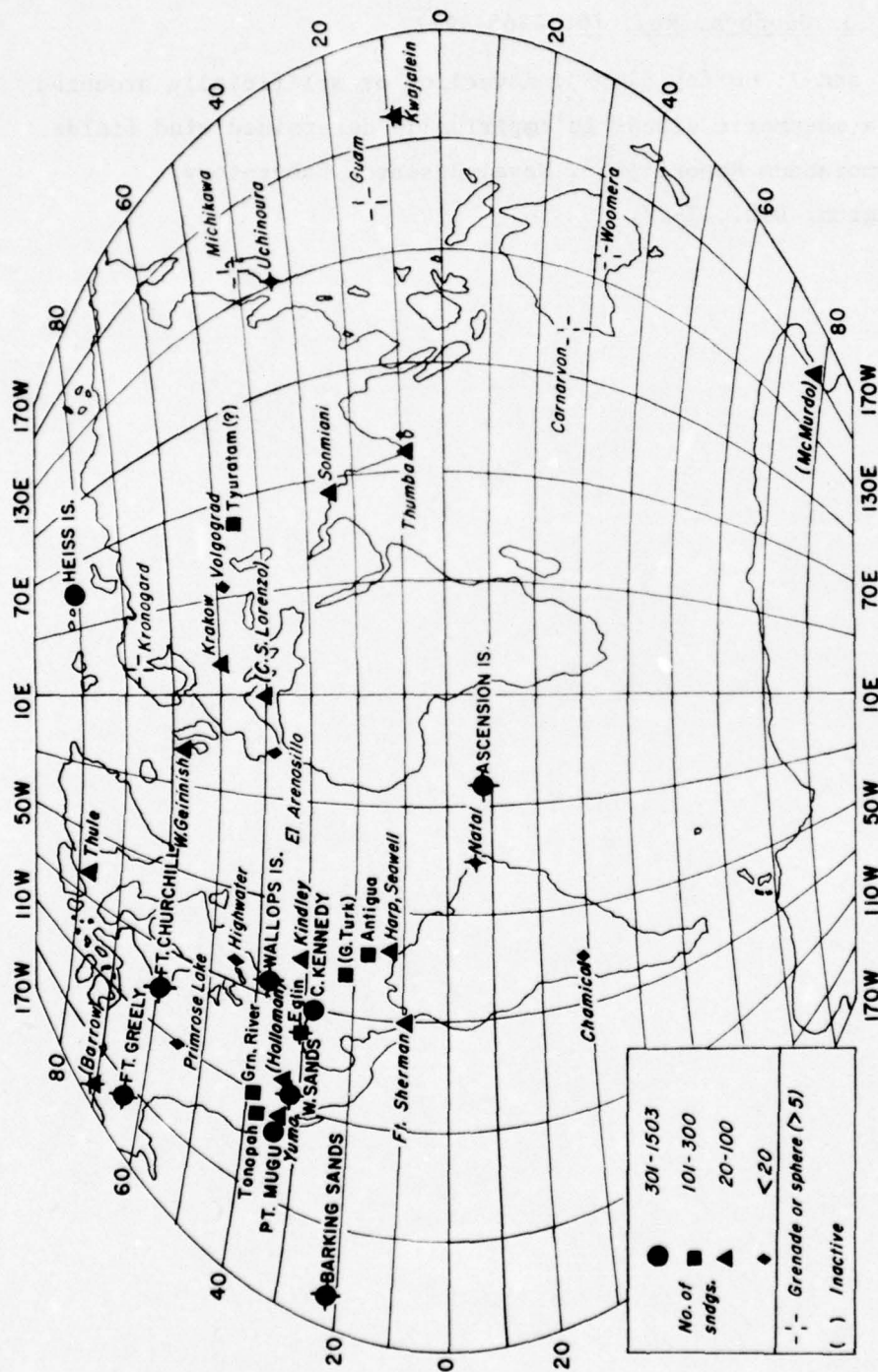
REFERENCES

- Baker, L. and D. Strobel (1975_a), Linear models of mesospheric circulation, NRL Memorandum Report 3101, 22 pp.
- Baker, L. and D. Strobel (1975_b), Linear models of mesospheric circulation II: development and applications of heating functions, NRL Memorandum Report , 15 pp.
- Belmont, A. D., D. G. Dartt and G. D. Nastrom (1975), Variations of stratospheric zonal winds, 20-65 km. 1961-1971, J. App. Met. 14, 585-594.
- Chapman, W. A., M. J. Cross, D. A. Flower, G. E. Peckham and S. D. Smith (1974), A spectral analysis of global atmospheric temperature fields observed by the selective chopper radiometer on the Nimbus 4 satellite during the year 1970-71, Proc. Roy. Soc. Lond. A. 338, 57-76.
- Charney, J. G. and P. G. Drazin (1961), Propagation of planetary-scale from the lower atmosphere into the upper atmosphere, J. Geophys. Res. 66, 83-109.
- Charney, J. G. and M. E. Stern (1962), On the stability of internal baro-clinic jets in a rotating atmosphere, J. Atmos. Sci. 19, 159-172.
- COSPAR International Reference Atmosphere (1965).
- COSPAR International Reference Atmosphere (1972).
- Dickinson, R. E. (1973) Baroclinic instability of an unbounded zonal shear flow in a compressible atmosphere, J. Atmos. Sci. 30, 1520-1527.
- Ebel, A. (1974), Heat and momentum sources of mean circulation at an altitude of 70 to 100 km, Tellus 26, 325-333.

- Glass, M. and A. Spizzichino (1974), Waves in the lower thermosphere: recent experimental investigations, J. Atmos. Terr. Phys. 36, 1825-1839.
- Groves, G. V. (1969_a), Wind models from 60 to 130 km altitude for different months and latitudes, J. Brit. Interplanet. Soc. 22, 285-307.
- Leovy, C. (1964), Simple models of thermally driven mesospheric circulation, J. Atmos. Sci. 21, 327-329.
- Leovy, C. and T. Ackerman (1973), Evidence for high-frequency synoptic disturbances near the strato pause, J. Atmos. Sci. 30, 940-941.
- Lindzen, R. S. (1967), Thermally driven diurnal tide in the atmosphere, Quart. J. R. Met. Soc. 93, 18-42.
- Kriester, B. (1972), Large scale circulation patterns of the stratosphere, Space Sci. Rev. 13, 258-273.
- Madala, R., S. A. Piacsek and S. T. Zalesak (1975), A semi-spectral numerical model for forced vertically propagating planetary waves, part I - application of the model to linear diurnal and semi-diurnal atmospheric thermal tides, NRL Memorandum Report 3145, 40 pp.
- Park, J. H. and J. London (1974), Ozone photochemistry and radiative heating of the middle atmosphere, J. Atmos. Sci. 31, 1898-1961.
- Quiroz, R. S. (1969), Meteorological rocket research since 1959 and current requirements for observation and analysis above 60 kilometers, NASA Contractor Report CR-1293, NASA, Washington, D.C., 1-66.
- Schoeberl, M. R. (1976), The propagation of planetary scale waves into the upper atmosphere, Ph.D. Thesis, University of Illinois, 1-270.
- Simmons, A. J. (1974), Baroclinic instability at the winter strato-pause, Quart. J. R. Met. Soc. 100, 531-540.

van Loon, H., R. L. Jenne and K. Labitzke (1973), Zonal harmonic standing waves, J. Geophys. Res. 78, 4463-4471.

Zalesak, S. and T. Coffey (1975), Advection of artificially produced upper atmospheric clouds in empirically determined wind fields, NRL Memorandum Report 3046, Naval Research Laboratory, Washington, D.C., 1-27.



Principal Meteorological Rocket Sites

Fig. 1 — Rocket network station locations as of 1968. Some significant modifications have occurred since then, such as the introduction of the Soviet Antarctic rocket program at Molodeynaya (68S, 46E) in 1969.

CIRA 1972

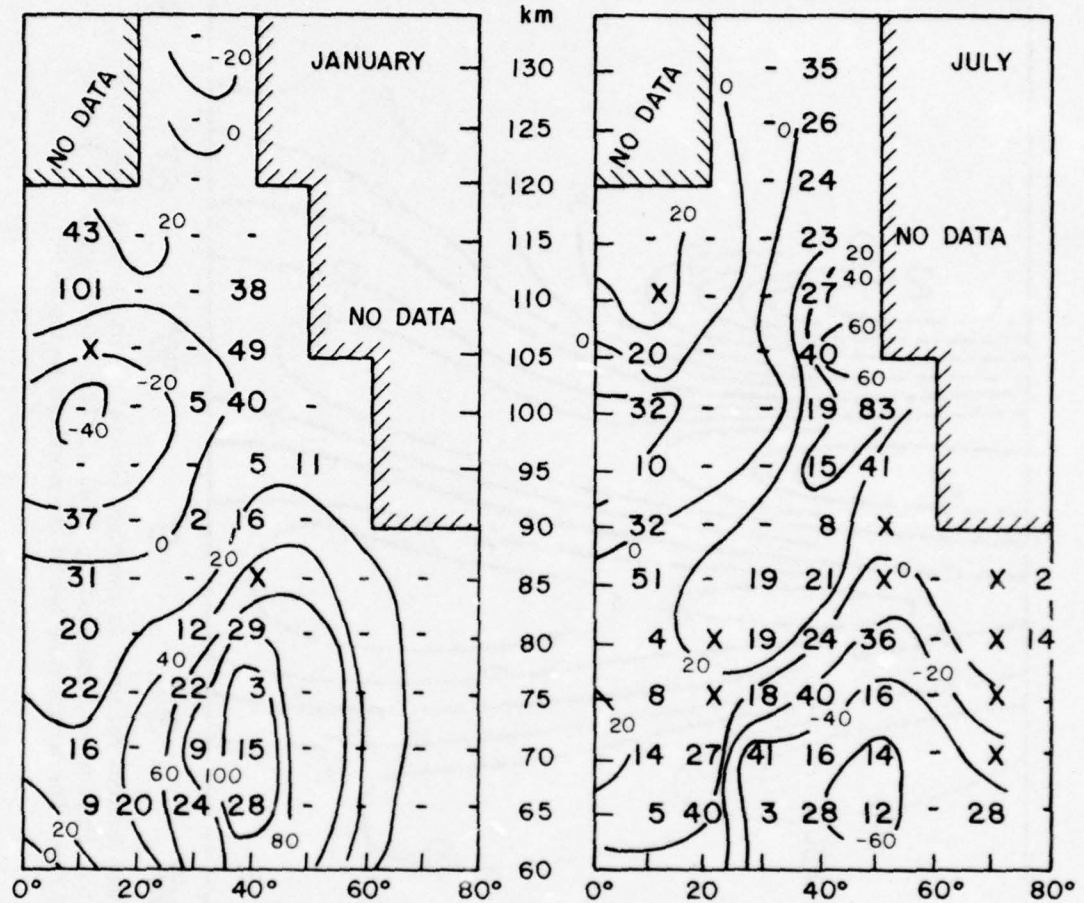


Fig. 2 — January and July statistical wind data used to construct the CIRA (1972) model atmosphere. Bold face numbers show the standard deviation in meters per second of the observational data at the indicated altitudes. X's indicate only a single measurement available; —'s indicate no measurements. Contours labeled with light numbers are model wind values in meters per second.

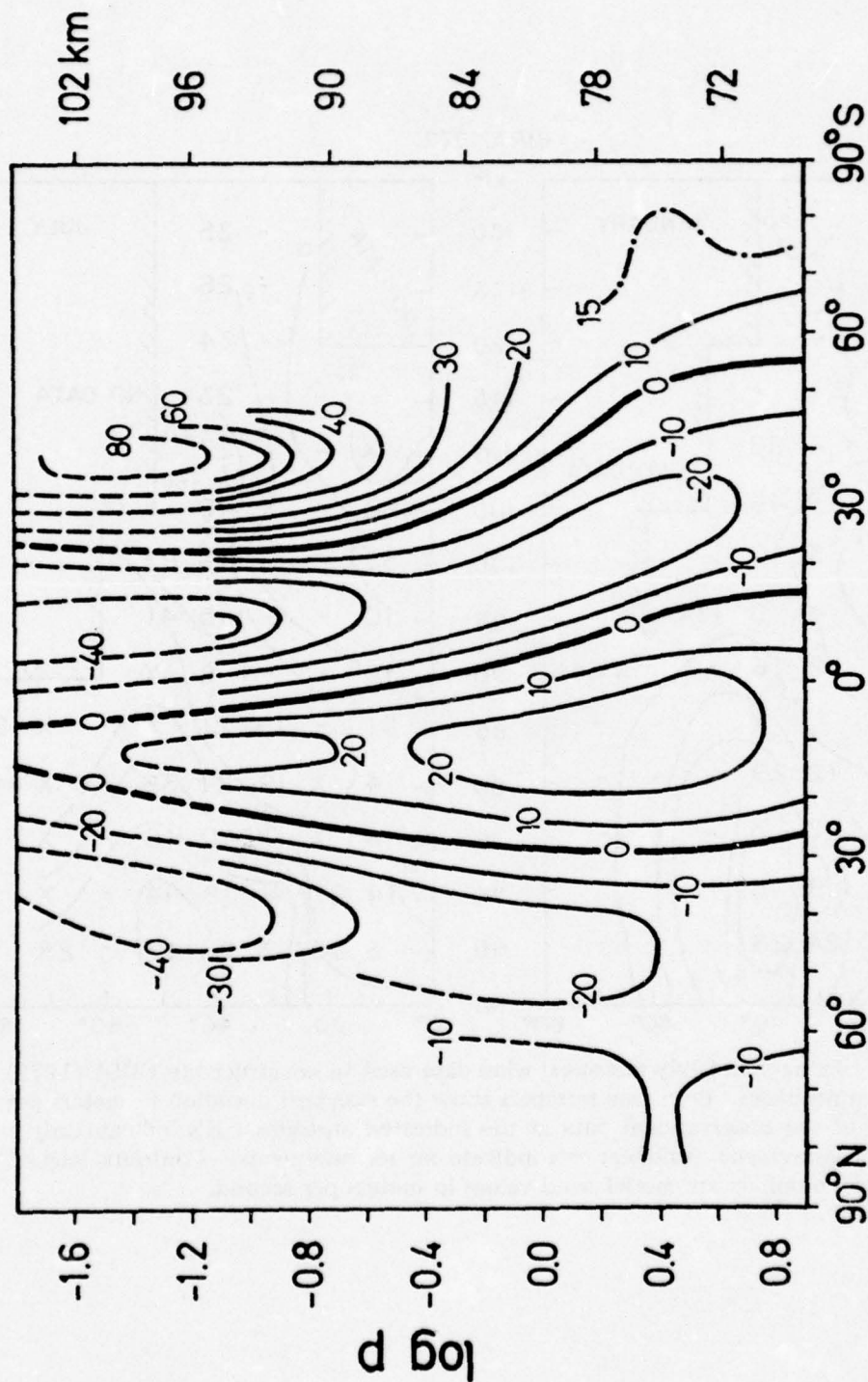


Fig. 3 — Heat sources required to maintain Groves' observationally based wind models during solstice as computed by Ebel (1974). Units are 10^{-5} K/S or 0.864K per day. The winter pole lies in the northern hemisphere.

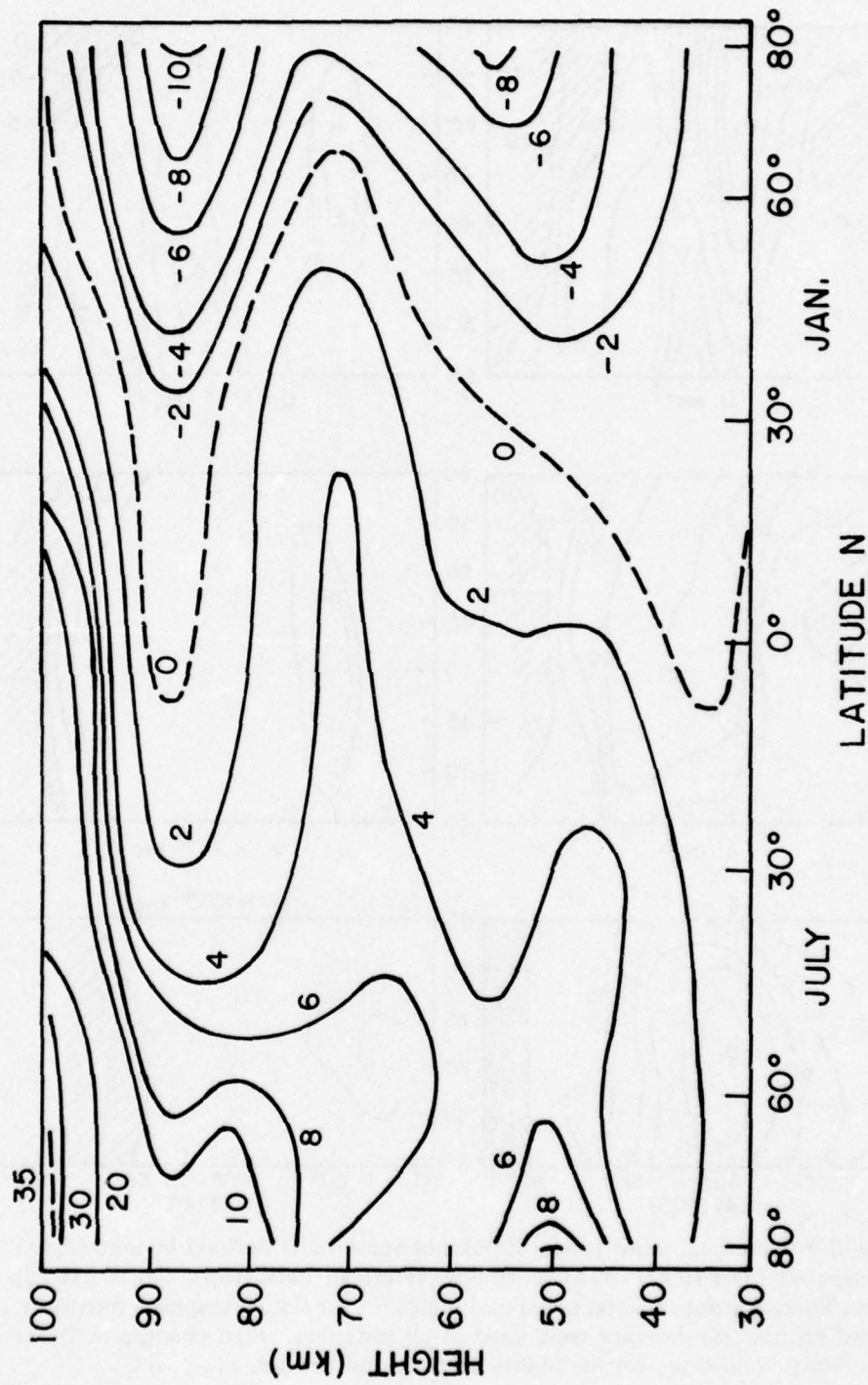


Fig. 4 — Theoretically computed heating rates for solstice conditions after Park and London (1974)

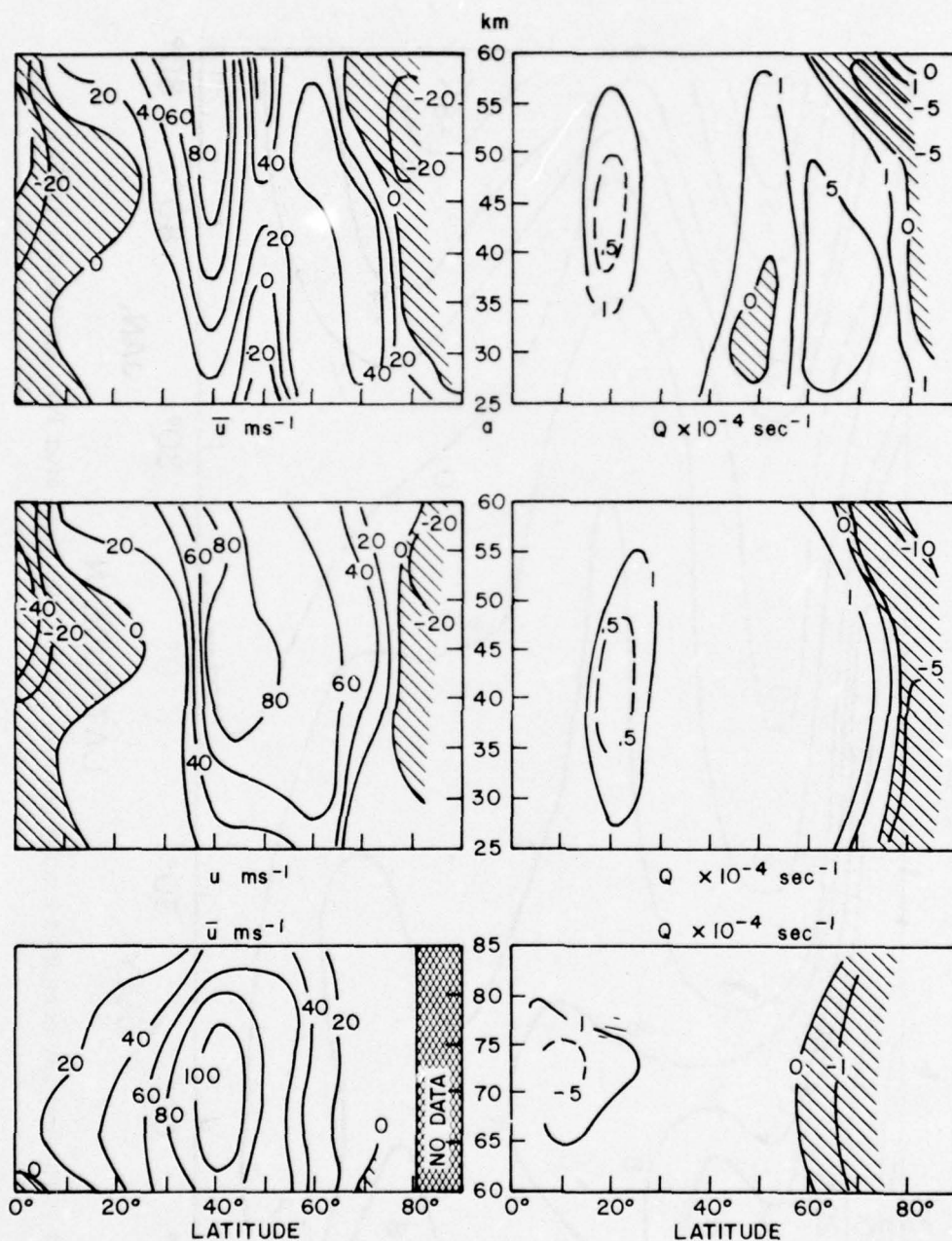


Fig. 5 — The zonal wind model (left) and value of Q defined in text (right) computed for CIRA (1972) Northern American data (top), CIRA (1972) West European data (center), and all longitudes for the mesosphere (bottom). Wind profiles for January were used in all instances. Sign changes in Q are necessary conditions for instability in the wind profile.

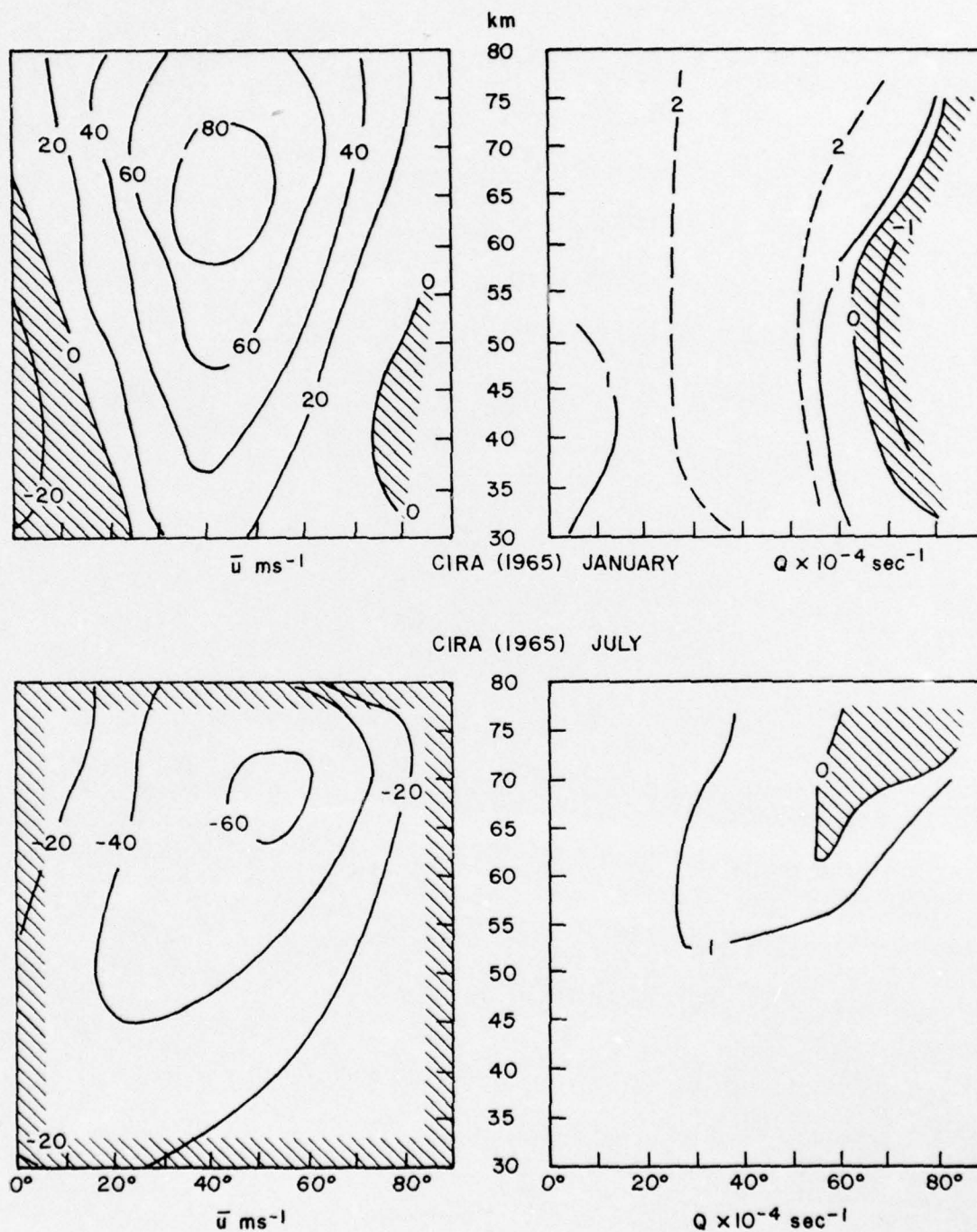


Fig. 6 — Same as Fig. 5 for CIRA (1965) model atmosphere for January and July

DISTRIBUTION LIST

DIRECTOR

Defense Advanced Rsch Proj Agency
Architect Building
1400 Wilson Blvd.
Arlington, VA 22209
ATTN: Strategic Tech Office
ATTN: LTC. W. A. Whitaker

Defense Communication Engineer Center
1860 Wiehle Avenue
Reston, VA 22090
ATTN: CODE R820 F. L. Crawford
ATTN: CODE R410 W. D. Dehart

DIRECTOR

Defense Communications Agency
Washington, D. C. 20305
ATTN: CODE 960
ATTN: CODE 480

Defense Documentation Center
Cameron Station
Alexandria, VA 22314 12 copies
ATTN: TC

DIRECTOR

Defense Intelligence Agency
Washington, D. C. 20301
ATTN: W. Wittig DC-7D
ATTN: DT-LB

DIRECTOR

Defense Nuclear Agency
Washington, D. C. 20305
ATTN: STSI Archives
ATTN: STVL
ATTN: STTL Tech Library 2 copies
ATTN: DDST
ATTN: RAAE

DIR OF DEFENSE RSCH & ENGINEERING
Washington, D. C. 20301
ATTN: DD/S&SS John B. Walsh
ATTN: OAD/EPS

COMMANDER
Field Command
Defense Nuclear Agency
Kirtland AFB, NM 87115
ATTN: FCPR

Interservice Nuclear Weapons School
Kirtland AFB, NM 87115
ATTN: Document Control

DIRECTOR
Joint Strat TGT Planning Staff Jcs
Offutt AFB
Omaha, NB 68113
ATTN: JLTW-2
ATTN: JPST G. D. Burton
ATTN: JPST MAJ. J. S. Green

CHIEF
Livermore Division Fld Command DNA
Lawrence Livermore Laboratory
P. O. Box 808
Livermore, CA 94550
ATTN: FCPRL

COMMANDER
National Military Comd Sys Support Ctr
Pentagon
Washington, D. C. 20301
ATTN: B211
ATTN: DP Director for CSPO

DIRECTOR
National Security Agency
Ft. George G. Meade, MD 20755
ATTN: W14 Pat Clark
ATTN: Frank Leonard

OJCS/J-3
Pentagon
Washington, D. C. 20301
ATTN: J-3 OPS ANAL BR. COL. Longberry

OJCS/J-6
Pentagon
Washington, D. C. 20301
ATTN: J-6

DIRECTOR
Telecommunications & Comd & Con Sys
Washington, D. C. 20301
ATTN: ASST DIR Info & Space Sys
ATTN: DEP ASST) SEC Sys

MANAGER
BMD Program Office
1300 Wilson Blvd.
Arlington, VA 22209
ATTN: Plans Division
ATTN: DACS-BMM

COMMANDER
Harry Diamond Laboratories
2800 Powder Mill Road
Adelphi, Md. 20783
ATTN: AMXDO-NP

COMMANDER
TRASANA
White Sands Missile Range, NM 88002
ATTN: EAB
ATTN: R. E. Dekinder, Jr.

DIRECTOR
U. S. Army Ballistic Research Labs
Aberdeen Proving Ground, MD. 21003
ATTN: AM-CA Franklin E. Niles

U. S. Army Communications CMD
C-E Services Division
Pentagon Rm. 2D513
Washington, D. C. 20310
ATTN: CEAD

COMMANDER
U. S. Army Electronics Command
Fort Monmouth, N. J. 07703
ATTN: AMSEL-TL-ENV HANS A) BOMKE

COMMANDER

U.S. Army Material Command
5001 Eisenhower Avenue
Alexandria, VA 22333

ATTN: AMCRD-WN-RE John F. Corrigan
ATTN: Director of Development

COMMANDER

U.S. Army Material Command
Foreign and Scientific Tech Center
220 - 7th St. N.E.
Charlottesville, VA 22901

ATTN: P. A. Crowley
ATTN: R. Jones

COMMANDER

U.S. Army Missile Command
Redstone Arsenal
Huntsville, AL 35809

ATTN: AMSMI-YTT W. G. Preussel, Jr.

COMMANDER

U.S. Army Nuclear Agency
Fort Bliss, TX 79916

ATTN: USANUA-W. J. Berbert

CHIEF OF NAVAL RESEARCH

Department of the Navy
Arlington, VA 22217

ATTN: CODE 418
ATTN: CODE 464 Jacob L. Warner

COMMANDER

Naval Air Systems Command
Headquarters
Washington, D. C. 21360

ATTN: AIR 5381

COMMANDER

Naval Electronics Systems Command
Naval Electronic Systems CMD HQS
Washington, D. C. 20360

ATTN: NAVALEX 034 T. Barry Hughes
ATTN: PME 106-1 Satellite Comm Project Off
ATTN: John E. Doncarlos
ATTN: PME 117

COMMANDER

Naval Electronics Laboratory Center
San Diego, CA 92152

ATTN: William F. Moler
ATTN: Code 2200 1 Verne E. Hildebrand
ATTN: R. Eastman

COMMANDING OFFICER

Naval Intelligence Support CTR
4301 Suitland Road, Bldg. 5
Washington, D. C. 20390

ATTN: Mr. Dubbin Stric 12

DIRECTOR

Naval Research Laboratory
Washington, D. C. 20375

ATTN: HDQ COMM DIR Bruce Wald
ATTN: CODE 5460 Radio Propagation BR
ATTN: CODE 7701 Jack D. Brown
ATTN: CODE 7700 Division Superintendent 25 copies

ATTN: CODE 7750 Branch Head 150 copies

COMMANDING OFFICER

Naval Space Surveillance System
Dahlgren, VA 22448

COMMANDER

Naval Surface Weapons Center
White Oak, Silver Spring, MD 20910

ATTN: CODE 730 Tech Lib.
ATTN: CODE 1224 Navy Nuc Prgms Off

DIRECTOR

Strategic Systems Project Office
Navy Department
Washington, D. C. 20376

ATTN: NSP-2141

COMMANDER

ADC/AD
ENT AFB, CO 80912
ATTN: ADDA

AF Cambridge Rsch Labs, AFSC
L. G. Hanscom Field
Bedford, MA 01730

ATTN: LKB Kenneth S. W. Champion
ATTN: OPR Alva R. Stair
ATTN: OPR James C. Ulwick

AF Weapons Laboratory, AFSC
Kirtland AFB, NM 87117

ATTN: DYT LT. Mark A. Fry
ATTN: CA Arthur H. Guenther
ATTN: John M. Kamm SAS

AFTAC

Patrick AFB, FL 32925

ATTN: TF MAJ. E. Hines
ATTN: TF/CAPT. Wiley
ATTN: TN

Air Force Avionics Laboratory, AFSC
Wright-Patterson AFB, OH 45433

ATTN: AFAL AVWE Wade T. Hunt

Assistant Chief of Staff
Studies and Analysis
Headquarters, U. S. Air Force
Washington, D. C. 20330

Headquarters
Electronic Systems Division, AFSC
L. G. Hanscom Field
Bedford, MA 01730

ATTN: XRE LT. Michaels
ATTN: LTC J. Morin CDEF XRC
ATTN: YSEV

COMMANDER
Foreign Technology Division, AFSC
Wright-Patterson AFB, OH 45433
ATTN: TD-BTA LIBRARY

HQ USAF/RD
Washington, D. C. 20330
ATTN: RDQ

COMMANDER
Rome Air Development Center, AFSC
Griffiss AFB, N. Y. 13440
ATTN: ENTLD Doc Library

COMMANDER IN CHIEF
Strategic Air Command
Offutt AFB, NB 68113
ATTN: XPFS MAJ. Brian G. Stephen

544IES
Offutt AFB, NB 68113
ATTN: RDPO Lt. Alan B. Merrill

Los Alamos Scientific Laboratory
P. O. Box 1663
Los Alamos, N. M. 87544
ATTN: DOC CON for R. F. Taschek
ATTN: DOC CON for John Zinn

Sandia Laboratories
P. O. Box 5800
Albuquerque, NM 87115
ATTN: DOC CON for A. Dean Thronbrough
ATTN: DOC CON for W. D. Brown
ATTN: DOC CON for D. A. Dahlgren, ORG 1722
ATTN: DOC CON for T. Wright

University of California
Lawrence Livermore Laboratory
P. O. Box 808
Livermore, CA 94550
ATTN: Tech Info Dept L-3

Department of Commerce
National Oceanic & Atmospheric Admin.
Environmental Research Laboratories
Boulder, CO 80302
ATTN: Joseph H. Pope
ATTN: C. L. Rufenach

Department of Commerce
Office of Telecommunications
Institute of Telecom Science
Boulder, CO 80302

ATTN: Glenn Falcon
ATTN: William F. Utlaut
ATTN: G. Reed
ATTN: L. A. Berry

Department of Transportation
Transportation Rsch. System Center
Kendall Square
Cambridge, MA 02142
ATTN: TER G. Harowles

NASA
Goddard Space Flight Center
Greenbelt, MD 29771
ATTN: CODE 750 T. Golden

NASA
600 Independence Ave., S. W.
Washington, D. C. 20546
ATTN: M. Dubin

Aerospace Corporation
P. O. Box 92957
ATTN: T. M. Salmi
ATTN: S. P. Bower
ATTN: B. Josephson
ATTN: SMFA for PW

Analytical Systems Corporation
25 Ray Avenue
Burlington, MA 01803
ATTN: Radio Sciences

Avco-Everett Research Laboratory, Inc.
2385 Revere Beach Parkway
Everett, MA 02149
ATTN: Richard M. Patrick

Bell Telephone Laboratories, Inc.
Mountain Avenue
Murray Hill, N. J. 07974
ATTN: Norman J. Zabusky

Boeing Company, The
P. O. Box 3707
Seattle, WA 98124
ATTN: D. Murray
ATTN: Glen Keister

Brown Engineering Company, The
Cummings Research Park
Huntsville, AL 35807
ATTN: David Lambert MS 18

California at San Diego, Univ of
Building 500 Mathews Campus
3172 Miramar Road
La Jolla, CA 92037
ATTN: Henry G. Booker

Calspan Corporation
P. O. Box 235
Buffalo, N.Y. 14221
ATTN: Romea A. Deliberis

Computer Sciences Corporation
P. O. Box 530
6565 Arlington Blvd.
Falls Church, VA 22046
ATTN: H. Blank
ATTN: Barbara F. Adams

Comstat Laboratories
P. O. Box 115
Clarksburg, MD 20734
ATTN: R. R. Taur

Cornell University
Department of Electrical Engineering
Ithaca, N. Y. 14850
ATTN: D. T. Farley, Jr.

EG&G, INC.
Los Alamos Division
P. O. Box 809
Los Alamos, N.M. 85544
ATTN: James R. Breedlove

ESL, Inc.
495 Java Drive
Sunnyvale, CA 93102
ATTN: J. Roberts
ATTN: V. L. Mower
ATTN: James Marshall
ATTN: R. K. Stevens

General Electric Company
Tempo-Center for Advanced Studies
816 State Street (P. O. Drawer QQ)
Santa Barbara, CA 93102
ATTN: Tom Barrett
ATTN: Don Chandler
ATTN: DASIAC
ATTN: Warren S. Knapp

General Electric Company
Space Division
Valley Forge Space Center
P. O. Box 8555
Philadelphia, PA 19101
ATTN: M. H. Bortner, Space Sci. Lab.

General Electric Company
P. O. Box 1122
Syracuse, N.Y. 13201
ATTN: F. A. Reibert

General Research Corporation
P. O. Box 3587
Santa Barbara, CA 93105
ATTN: John Ise, Jr.

Geophysical Institute
University of Alaska
Fairbanks, AK 99701
ATTN: Technical Library
ATTN: Neil Brown
ATTN: T. N. Davis

GTE Sylvania, Inc.
189 B. Street
ATTN: Marshal Cross

HRB-Singer, Inc.
Science Park, Science Park Road
P. O. Box 60
State College, PA 16801
ATTN: Larry Feathers

Illinois, University of
Department of Electrical Engineering
Urbana, IL 61801
ATTN: K. C. Yeh

Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202
ATTN: Ernest Bauer
ATTN: Hans Wolfhard
ATTN: J. M. Aein
ATTN: Joel Bengston

Intl Tel & Telegraph Corporation
500 Washington, Ave.
Nutley, N. J. 07110
ATTN: Technical Library

ITT Electro-Physics Laboratories, Inc.
9140 Old Annapolis Road
Columbia, MD 21043
ATTN: John M. Kelso

Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, MD 20910
ATTN: Document Librarian

Lockheed Missiles & Space Co., Inc.
P. O. Box 504
Sunnyvale, CA 94088
ATTN: Dept 60-12

Lockheed Missiles & Space Company
3251 Hanover Street
Palo Alto, CA 94304
ATTN: Billy M. McCormac, Dept 52-14
ATTN: Martin Walt, Dept 52-10
ATTN: Richard G. Johnson, Dept. 52-12

MIT Lincoln Laboratory

P. O. Box 73

Lexington, MA 02173

ATTN: Mr. Walden, X113

ATTN: D. Clark

ATTN: James H. Pannell L-246

ATTN: Lib A-082 for David M. Towle

Martin Marietta Corporation

Denver Distribution

P. O. Box 179

Denver, CO 80201

ATTN: Special Projects Program 248

Maxwell Laboratories, Inc.

9244 Balboa Avenue

San Diego, CA 92123

ATTN: A. J. Shannon

ATTN: V. Fargo

ATTN: A. N. Rostocker

McDonnell Douglas Corporation

5301 Bolsa Avenue

Huntington Beach, CA 92647

ATTN: J. Moule

ATTN: N. Harris

Mission Research Corporation

735 State Street

Santa Barbara, CA 93101

ATTN: R. Hendrick

ATTN: Conrad L. Longmire

ATTN: R. E. Rosenthal

ATTN: R. Bougusch

ATTN: David Sowle

ATTN: M. Scheibe

ATTN: D. Sappenfield

ATTN: P. Fischer

ATTN: Ralph Kilb

Mitre Corporation, The
Route 62 and Middlesex Turnpike
P. O. Box 208
Bedford, MA 01730

ATTN: S. A. Morin M/S
ATTN: Chief Scientist W. Sen
ATTN: G. Harding

Mitre Corporation, The
Westgate Research Park
1820 Dolley Madison Blvd.
McLean, VA 22101

ATTN: Allen Schneider

North Carolina State Univ at Raleigh
North Carolina State Univ Campus
Raleigh, N.C. 27507

ATTN: SEC Officer for Walter A. Flood

Pacific-Sierra Research Corp.
1456 Cloverfield Blvd.
Santa Monica, CA 90404

ATTN: E. C. Field, Jr.

Philco-Ford Corporation
Western Development Laboratories Div
3939 Fabian Way
Palo Alto, CA 94303

ATTN: J. T. Mattingley MS X22

Photometrics, Inc.
442 Marrett Road
Lexington, MA 02173

ATTN: Irving L. Kofsky

Physical Dynamics, Inc.
P. O. Box 1069
Berkeley, CA 94701

ATTN: Joseph B. Workman

R&D Associates
P. O. Box 3580
Santa Monica, CA 90403

ATTN: Robert E. Lelevier
ATTN: Forest Gilmore
ATTN: Richard Latter
ATTN: William B. Wright, Jr.

Rand Corporation, The
1700 Main Street
Santa Monica, CA 90406
ATTN: Cullen Crain

Science Applications, Inc.
P. O. Box 2351
La Jolla, CA 92038
ATTN: Daniel A. Hamlin
ATTN: D. Sachs
ATTN: E. A. Straker

Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, CA 94025
ATTN: L. L. Cobb
ATTN: Walter G. Chestnut
ATTN: Thomas A. Croft
ATTN: Donald Neilson
ATTN: David A. Johnson
ATTN: Charles L. Rino
ATTN: E. J. Fremouw

Stanford Research Institute
306 Wynn Drive, N. W.
Huntsville, AL 35805
ATTN: Dale H. Davis

Tri-Com, Inc.
12216 Parklawn Place
Rockville, MD 20852
ATTN: Darrell Murray

TRW Systems Group
One Space Park
Redondo Beach, CA 90278
ATTN: P. H. Katsos
ATTN: J. W. Lowry

Visidyne, Inc.
19 Third Avenue
North West Industrial Park
Burlington, MA 01803
ATTN: Oscar Manley